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ScienceDirect

Energy Procedia 54 (2014) 2 – 10

Energy Procedia

4th International Conference on Advances in Energy Research 2013, ICAER 2013

Solar parabolic dish thermoelectric generator with acrylic cover

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Abstract

The use of solar energy in the production of electricity is gaining momentum for obvious reasons. This article presents an experimental model of thermoelectric generator driven by a solar parabolic dish collector having open mouth diameter of 3.56 m with focal length of 1.11 m. The focal receiver is embedded by flat thermoelectric modules with an absorber plate and it is enclosed in an acrylic cover. Experiments were conducted at a constant flow rate of heat transfer fluid of water. There is a substantial increase in the overall efficiency of the system. An Empirical relationship to find the system efficiency, over a range of solar beam radiation, with and without cover is also presented

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*Keywords:*Solar parabolic dish collector; thermoelectric module; receiver plate; acrylic cover; overall efficiency.

1. Introduction and experimental setup

Thermoelectric generators use Seebeck effect that a potential difference proportional to the temperature difference is set up across the two faces of TEG. The temperature difference is achieved by placing the hot face of the TEG at the focus of a parabolic dish while the other face is kept at a lower temperature with cold water passing over it.The arrangement is shown in schematic diagram (Fig.1).

The natural convection and radiation heat losses from the receiver substantially reduce the performance of the system. A moderate temperature rise leads to a considerable heat loss, which may directly influence the performance of dish system. Therefore, the effect of combined natural convection and surface radiation on total heat loss needs to be investigated [1].

In order to get the maximum power, an advanced mechanism of heat transfer should be established with good insulation to avoid the strong impact of fluctuations on ambient condition. In this article, an attempt is made to increase the TEG performance with perfectly insulated heat sink and acrylic cover that encloses the receiver plate.

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Selection and peer-review under responsibility of Organizing Committee of ICAER 2013
doi:10.1016/j.egypro.2014.07.244

Nomenclature

A_c	Aperture area of the collector	(m^2)
A_r	Receiver surface area	(m^2)
I	The electric current	(A)
I_b	Solar beam radiation	(W/m^2)
K_{teg}	Thermal conductivity of module	(W/m^2K)
Q_s	Amount of heat supplied	(W)
Q_u	Amount of heat gained	(W)
R_L	The load resistance	(Ohm)
S	Seebeck coefficient of thermoelectric material	(V/K)
T_a	Ambient temperature	(K)

Greek Letters

ρ	Reflectivity of concentrator surface
α	Absorptivity of receiver surface

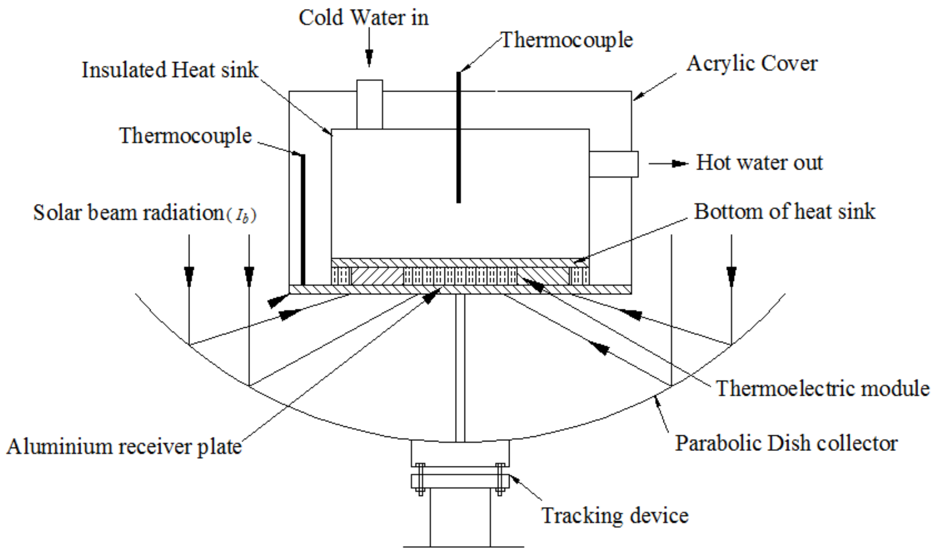

Fig. 1. Arrangement of solar parabolic dish thermoelectric generator.

Figure 1 illustrates the arrangement of solar parabolic dish thermoelectric generator. It consists of a parabolic dish collector (PDC), a flat aluminium receiver plate attached with thermoelectric modules on its focal plane and an acrylic cover that encloses the receiver plate. Thermoelectric modules are connected electrically in series and thermally in parallel between the receiver plate and the bottom surface of the heat sink that acts as heat exchanger. The hot side of the thermoelectric module is the top surface of the receiver plate and its cold side is the bottom surface of the heat sink. The heat sink is well insulated by ceramic fiber blankets. The heat sink and top surface of the receiver plate are covered by 3 mm acrylic box in order to avoid heat loss due to radiation. Thermal conductivity

and transmissivity of the acrylic sheet are 1.3 W/mK and 0.83 respectively. The parabolic dish collector is tracked manually in the east west direction to absorb the solar beam radiation on the bottom of the receiver unit.

1.1. The Dish Concentrator

The reflector surface was made by 20 triangular pieces of aluminium sheet polished on one side, fixed on the aluminium rib by a set of bolts and nuts. It also describes the sun tracking system unit by manual tilting of the parabolic dish by adjusting the bolt at the base plate to capture solar energy. The whole arrangement is mounted on a frame supported with an adjusting bolt for tilting the parabolic dish collector to different angles so that the sun is always directed to the collector at different time of the day. The design parameters of the solar PDC are given in Table 1.

Table 1. Design specification of solar parabolic dish concentrator.

Diameter of the open mouth of parabola	3.56 m
Parabolic concentrator surface area	10.53 m^2
Height of the parabola	0.7 m
Reflectivity of the concentrator	0.78
Focal distance	1.11 m

1.2. Receiver Unit

The receiver plate surface exposed to aperture area of the dish is coated with black paint to absorb the concentrated solar radiation to retain it and to drive the thermoelectric generator. The quantity of heat absorbed by the receiver plate depends mainly on the reflectivity and absorptivity of the material. The receiver plate is 2 mm thick and has an area of 0.1 m^2.

1.3. Description of the heat sink

The water cooled heat sink extracts the waste heat from the thermoelectric modules and thus helps to maintain the temperature of the cold face as low as possible. Bottom of heat sink is made up of aluminium and its sides are of acrylic material. The size of the sink is 200 × 200 × 100 mm and acrylic sheet is 5mm thick. A thermocouple is fixed in the middle of the heat sink for measuring the bulk temperature of water.

1.4. Thermoelectric module

The thermoelectric generator uses n-type and p-type bismuth telluride semiconductors. In the TEG system, four series-connected thermoelectric modules with individual dimensions of 56 × 56 mm and 127 p-n junctions per module were used. The thermoelectric module generates DC electricity as long as there is a temperature difference across the module.

2. Thermal analysis of the system

The absorbed solar energy (Q_s) by the receiver having absorptivity (α), transmissivity (τ), reflectivity of the reflecting surface of PDC (ρ), intercept factor (γ), and solar beam radiation (I_b) incident on the concentrator surface is expressed as,

$$Q_s = A_c \gamma \rho \alpha \tau I_b \tag{1}$$

The useful energy gained (Q_u) in the hot side of TEG is expressed mathematically

$$Q_u = Q_s - [h_w A_r (T_m - T_a) + \sigma \varepsilon A_r (T_m^4 - T_a^4)] \quad (2)$$

If the wind is flowing over the receiver plate surface at V m/sec, the heat loss coefficient due to the wind h_w, is given by the expression [2, 3].

$$h_w = 5.7 + 3.8V \quad (3)$$

The instantaneous thermal efficiency of the parabolic dish collector is found from the expression

$$\eta_r = \frac{Q_u}{A_c I_b} \quad (4)$$

The energy balance equation for TEG is written by assuming steady state operation. The output from TEG (P_{teg}) is estimated from the following relation,

$$P_{teg} = Q_h - Q_c \quad (5)$$

The amount of heat removed from cold side (Q_c) and hot side heat flow (Q_h) of the TEG are given by [3, 4].

$$Q_c = SIT_h + K_{teg}(T_h - T_c) + 0.5I^2 R_L \quad (6)$$

$$Q_h = SIT_c + K_{teg}(T_h - T_c) - 0.5I^2 R_L \quad (7)$$

Where T_h is the hot side temperature, and T_c is the cold side temperature. The energy efficiency of TEG is expressed as,

$$\eta_{teg} = \frac{P_{teg}}{Q_h} \quad (8)$$

The overall efficiency of the system is expressed as

$$\eta_{overall} = \eta_o \eta_r \eta_{teg} \quad (9)$$

The optical efficiency of the solar parabolic dish collector depends on the reflectivity of the concentrator surface and absorptivity of the receiving surface. Figure 2 presents the absorptivity of the receiver surface, tested for different spectral wave lengths using a UV spectrophotometer at the Department of Physics, National Institute of Technology Tiruchirappalli, India. The average absorptivity value is 0.96. The reflectance of the polished aluminium sheet is 0.68 is considered [5].

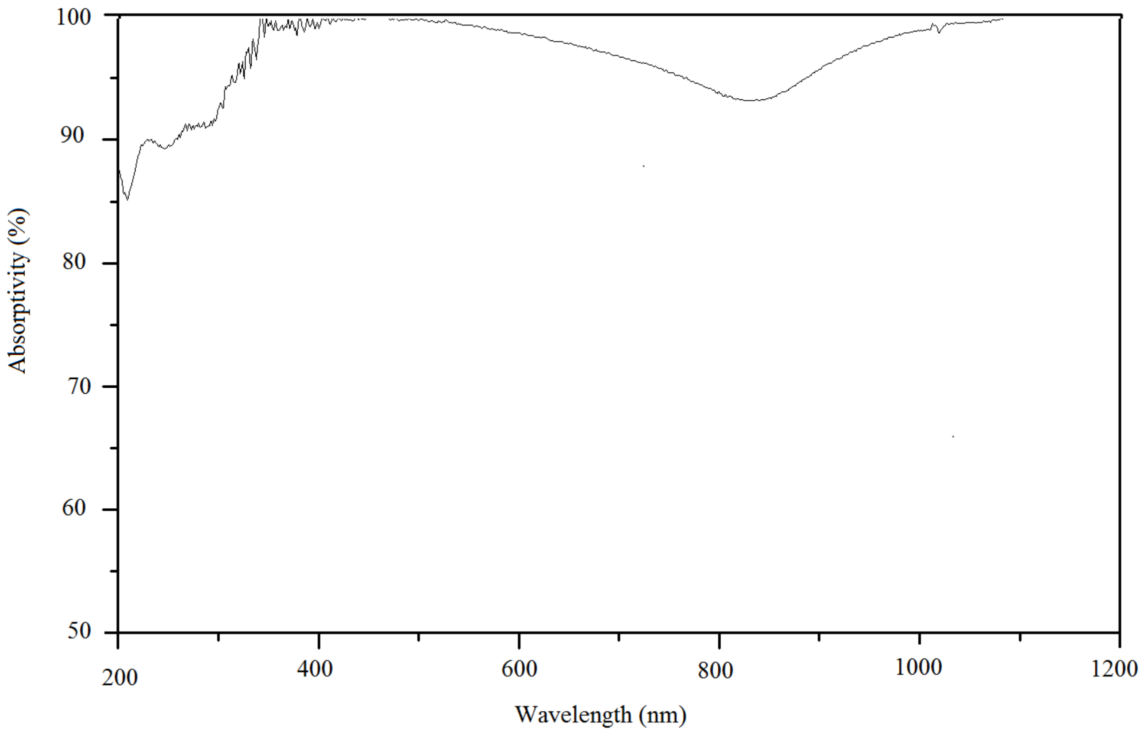

Fig. 2. Absorptivity of the black coated aluminium sheet for various spectral wave lengths.

Readings were noted down from 10.00 AM to 01.30 PM for every 30 min interval from March 11, 2012 to March 27, 2012. The ambient temperature, receiver plate temperature and bulk temperature of heat sink were measured by using K type thermocouples. Hot wire anemometer was used to measure the wind velocity. A pyranometer was used to measure the solar beam radiation.

3. Results and discussion

Figure 3 shows the variation of receiver plate temperature over the measured solar beam radiation. The maximum receiver plate temperature obtained was 383 K at the solar beam radiation of 1050 W/m^2 while the minimum temperature of 326 K with solar beam radiation of 600 W/m^2 in modified TEG. It should be noted that the receiver plate temperature is higher than the TEG without cover for the same solar beam radiation. By using cover in TEG, radiation heat loss from the top surface of the receiver is reduced. The results show that with increasing solar beam radiation there is an increase in receiver plate temperature.

Figure 4 shows the variation of Instantaneous thermal efficiency of the parabolic dish over the measured solar beam radiation. The maximum instantaneous thermal efficiency of parabolic dish is 67 % at the solar beam radiation of 600 W/m^2 in modified TEG. It decreases sharply as the operating temperature increases. This is due to the fact that, the receiver plate temperature in the TEG with cover is higher than the TEG without cover for the same solar beam radiation. Because of this higher temperature, the convective and radiative heat losses are high. So instantaneous thermal efficiency of dish in the TEG with cover is lower than that of TEG without cover.

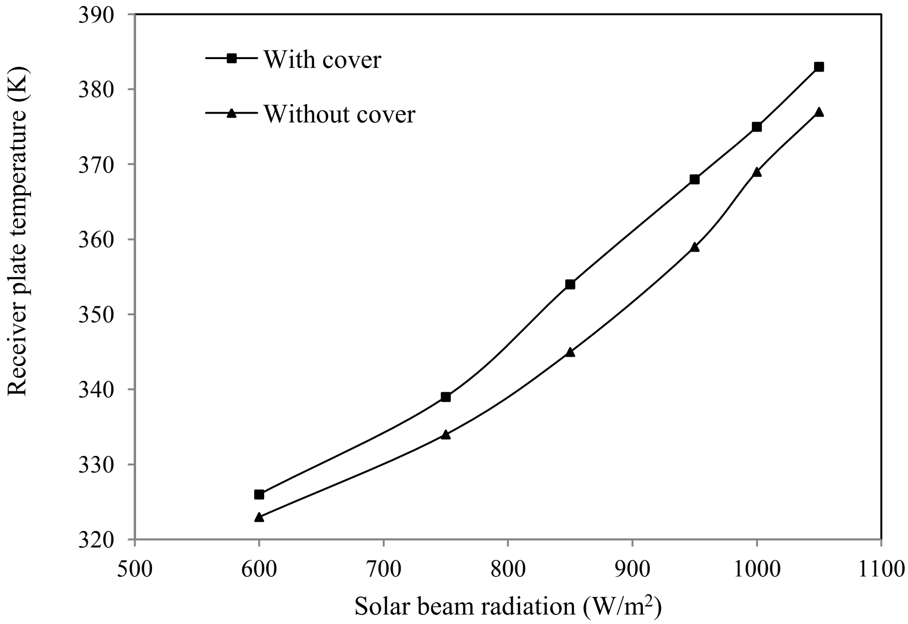

Fig. 3. Variations of receiver plate temperature with solar beam radiation

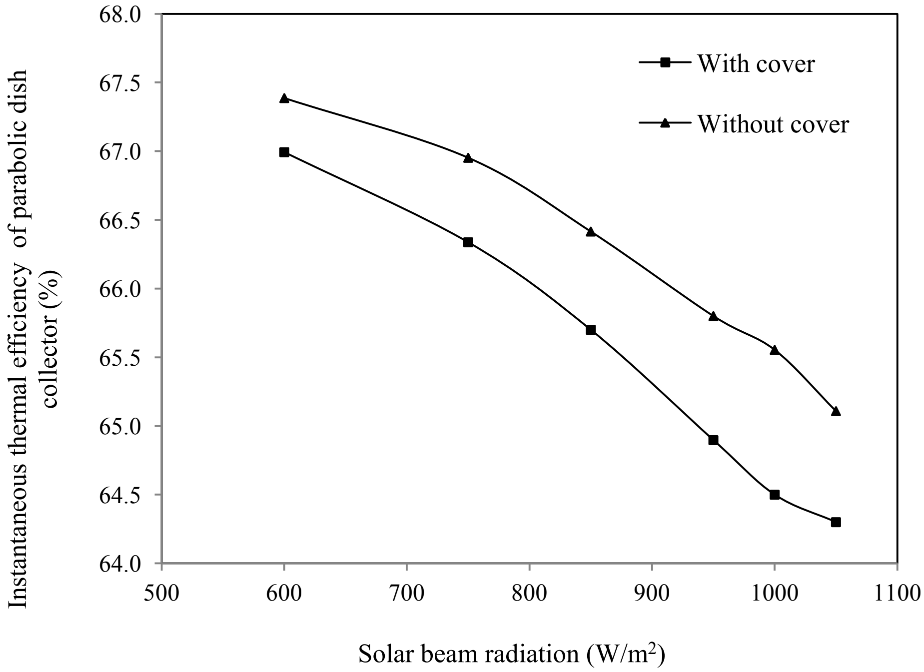

Fig. 4. Variation of Instantaneous thermal efficiency of collector with solar beam radiation

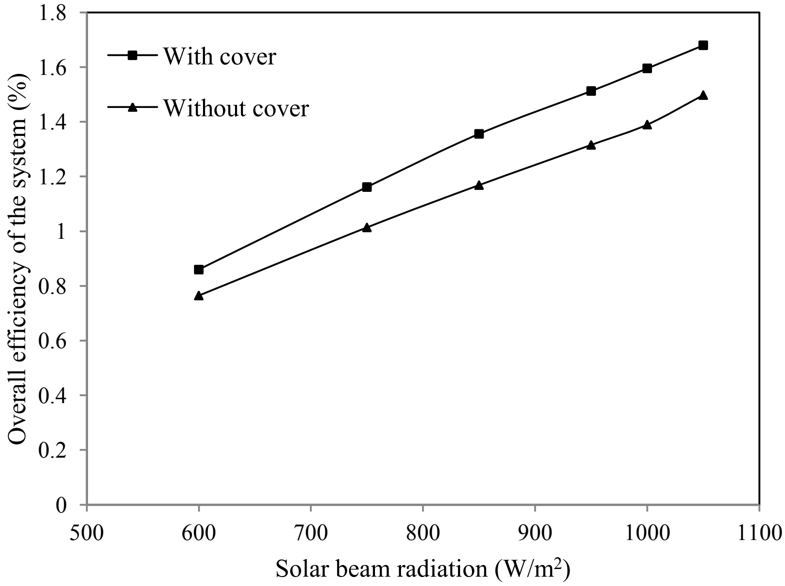

Fig. 5. Variation of overall efficiency of the System with solar beam radiation

Figure 5 shows the variation of overall efficiency of the system over the measured solar beam radiation. Many factors strongly affect the overall efficiency of the TEG, resulting in a nonlinear response. The system has overall efficiency of 1.68 % at the solar beam radiation of 1050 W/m^2 in modified TEG. There is a considerable improvement in overall efficiency for TEG with cover as compared to that without cover. The following correlation was obtained to compute the overall efficiency for any solar beam radiation using the experimental data, the R^2 value of the equation being 0.9995.

$$\eta_{overall} = -10^{-9} I_b^3 + 2 \times 10^{-6} I_b^2 + 0.0004 I_b \qquad \text{for} \quad 600 < I_b < 1050$$

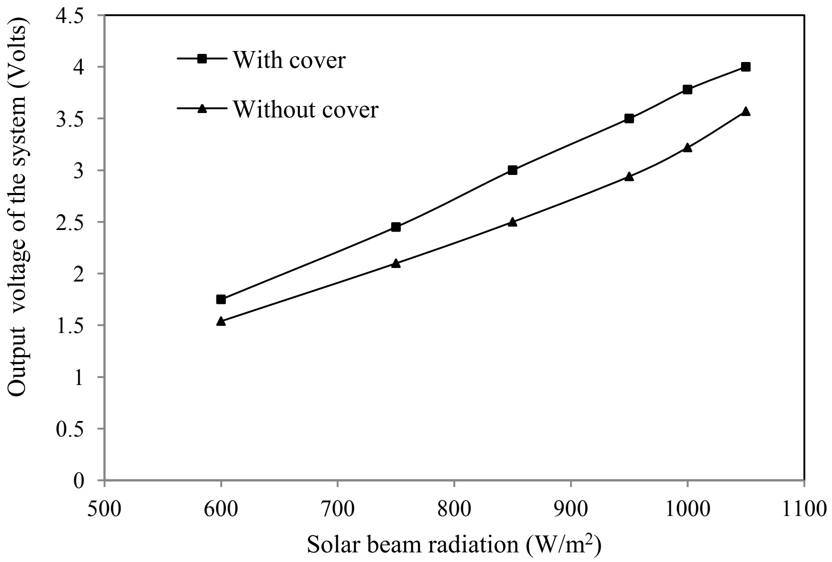

Fig. 6. The output voltage for various solar beam radiations

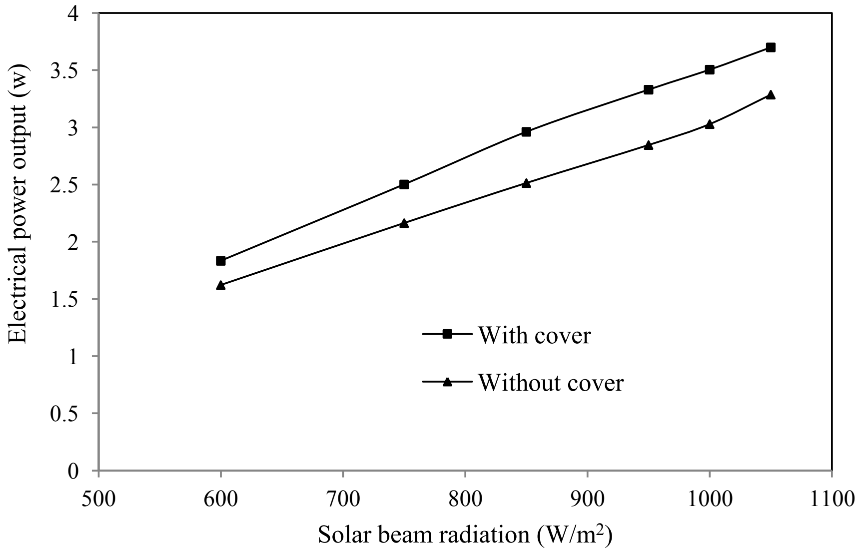

Fig. 7. Electrical power output for various solar beam radiations

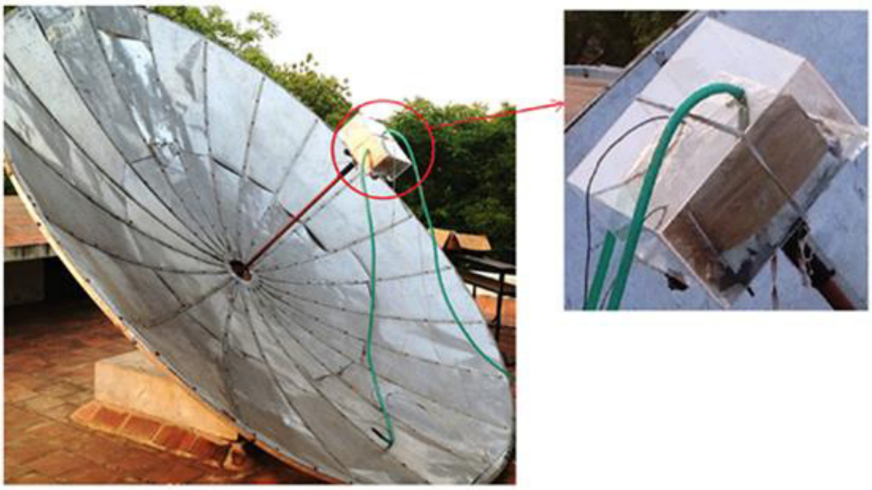

Fig. 8. Photographic view of solar parabolic dish thermoelectric generator

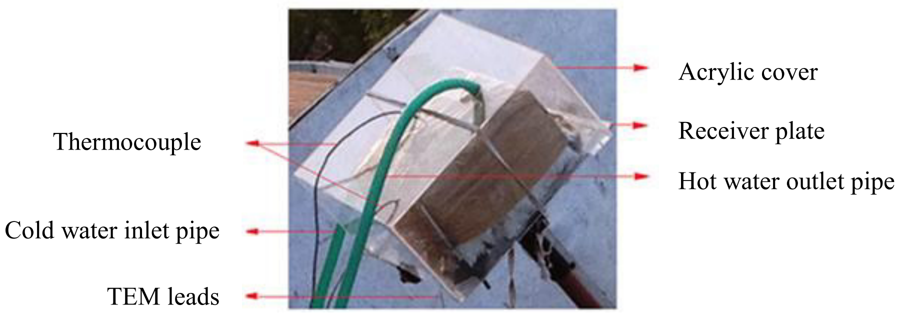

Fig. 9. Photograph view of thermoelectric generator receiver unit

Figures 6 and 7 show the electric characteristics of the TEG system for four thermoelectric modules electrically connected in parallel that reached a power output of 3.7 W for the solar beam radiation 1050 W/m^2. The results show that the power output increased significantly with increase in solar beam radiation. Figures 8 and 9 show the thermoelectric generator as placed in the focal area of the parabolic concentrator and arrangement of solar parabolic dish thermoelectric generator.

4. Conclusions

The potential of a concentrated solar power generation system based on thermoelectric module has been discussed. An experimental prototype concentrator thermoelectric generator using a parabolic dish concentrator was fabricated and tested. The following conclusions are drawn from the present study.

1. A maximum of 383 K receiver plate temperature was obtained for TEG with cover at solar beam radiation of 1050 W/m^2. It is 1.56% higher than in TEG without cover for the same solar beam radiation.
2. There is 2.11% improvement in overall efficiency for TEG with cover as compared to that without cover.
3. The maximum voltage of the thermoelectric module achieved was 4 volts, which is 10.75% higher than TEG without cover for same solar beam radiation. The electrical power output for modified TEG was 2.51% higher than that of the TEG without cover.

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References

[1] Reddy K.S, Sendhil Kumar N. Combined laminar natural convection and surface radiation heat transfer in a modified cavity receiver of solar parabolic dish. International Journal of Thermal Sciences 2008; 47:1647–1657.

[2] Sukhatme S.P, Nayak J.K. Solar energy: principles of thermal collection and storage. 2nd ed. New Delhi; Tata McGraw Hill ; 2012.

[3] Shanmugam S, Eswaramoorthy M, Veerappan AR. Mathematical modeling of thermoelectric generator driven by solar parabolic dish collector. Applied Solar Energy 2011; 47(1):31–35.

[4] Eswaramoorthy M, Shanmugam S. Numerical Model to compute heat loss in focal receiver of solar parabolic dish thermoelectric generator, Energy Sources, Part A: Recovery, Utilization Environmental Effects 2012; 34:959-965.

[5] Eswaramoorthy M. Studies on solar parabolic dish thermoelectric generator, Ph.D. thesis, 2010.